CHAPTER VIII

VIII. BOTTOM SEDIMENT COMPOSITION

A. Introduction

Lake sediments have proved to be of extreme importance to limnologists because they play an important role in the determination of nutrient levels and productivity in the overlying waters.

A review of the factors that may affect sediment-water exchange reactions shows that insufficient information is available at the present time to predict the extent and, in many cases, the net direction of exchange for many compounds in most natural waters. The sediments of a lake potentially represent a buffer system for many elements which could control concentrations in the overlying waters, because of the significant concentrations of some elements present in the sediments. The effect of this buffer system could be to keep the concentrations in the overlying waters relatively constant even though the concentrations of the element in the inflowing waters vary greatly (Lee, 1970).

One of the most important reactions of this type is the exchange of phosphorus between a lake's sediments and the overlying waters as related to the eutrophication of the waters. Lee (1970) states that lake sediments typically contain one to two parts per thousand of phosphorus per kilogram of dry sediment.

Knowledge is particularly lacking on the role of lake sediments in maintaining phosphate levels in water. It is not known if the sediments of a lake act as a sink in which the majority of the phosphorus present is refractory, i.e., not available for exchange reactions.

Frink (1967) suggests that the center of a lake acts as a reservoir for both total and available nitrogen and phosphorus. He concludes that nutrients which accumulate in the bottom of a lake as eutrophication proceeds constitute a vast reservoir apparently capable of supporting plant growth in the event nutrient input is reduced. This was the case at Kezar Lake, North Sutton, New Hampshire. Even after phosphorus loading was dramatically reduced from a point source, phytoplankton blooms continued on an annual basis. Phosphorus rich sediments continued releasing phosphorus into the upper water column supporting a vast population of phytoplankton (Connor and Smith, 1983).

In-lake mass balancing of phosphorus (Chapter VII) reveals that phosphorus uptake and release is probably occurring. It appears that the nutrient enriched, mucky sediments of deeper waters are releasing phosphorus to the hypolimnion during periods of anaerobiosis (no dissolved oxygen). Hypolimnetic phosphorus accumulation occurred as presented in Table V-14, Table V-15 and Figure V-4. During this same period and other periods througout the year, shallower sections of the lake were uptaking available phosphorus.

In addition to phosphorus, metal concentrations in the sediment can play a role in the ecological health of a lake. With the increasing concern with acidic precipitation in New Hampshire, lake or pond pH and ANC have become increasingly important concerns. Studies have shown various apparent mechanisms of response of the lake's biota to increased acidity, ranging from direct toxicity of hydrogen ion to disruptions of normal food-chain relations, behavioral patterns of animals, and biogeochemical cycles in the lake. Recent studies have shown increasing concentrations of heavy metals such as manganese, aluminum and zinc as a result of pH depressions below five units.

B. Chemical Characterization

A Wildco KB^{tm} coring device was utilized to extract an 11 inch and 13 inch sediment core. The cores were collected from the deepest location of Webster Lake and sectioned off into one inch upper, two inch middle and three to four inch bottom sediment column intervals. One gram from each sediment interval was digested with 10 mLs of ultra pure nitric acid utilizing a CEM microwave closed vessel digester for 40 minutes and analyzed for recoverable aluminum, cadmium, copper, iron, lead, manganese and zinc. Metals from previous studies were digested on a hot plate with 10 mLs of ultra pure nitric acid and a final treatment with peroxide. Results from the two digestion methods are presented in Table VIII-2. Only the microwave methods results are discussed in the following text. Sediment phosphorus concentrations for all cores were determined colormetrically after nitric and sulfuric block digestion. Such measurements could reflect deposition rates, toxic metal concentrations, phosphorus sediment accumulation, and spatial variability over time. Comparisons of other lake sediment core analyses performed in New Hampshire are presented in Table VIII-1.

Table VIII-1. Comparison of Surface Sediments (first inch) of some New Hampshire Lakes and Ponds.

Parameter/lake	Classification	Al	Cd	Cu	Fe	Pb	Mn	Zn	Tp
* Webster Lake Franklin	Mesotrophic	20,500	1.0	17	26,000	94	798	140	4,735
Mtn. Pond Chatham	Oligotrophic	25,120	<24	<80	16,320	97		184	4,530
Mendums Pond Barrington	Oligotrophic	16,800	<4	<80	13,120	100	180	80	7,128
Loon Lake Plymouth	Mesotrophic	14,921	<23	<80	30,595	47		158	7,211
Kezar Lake Sutton	Eutrophic	23,585	<236	830	16,038	58	283	6,604	5,569
French's Pond Henniker	Eutrophic	16,812	<30	69.3	27,525	723	832	317	10,165

All values in mg/kg dry weight of sediment

*Method utilizing CEM microwave (except Tp)

Table VIII-2.
Comparison of microwave and hotplate digestion methods in two Webster Lake sediment studies. Values presented are whole sediment core mean values $\pm$ one standard deviation.

Metal	Microwave	Hot Plate
Al	15593 $\pm$ 7031	9801 $\pm$ 6405
Ca	0.92 $\pm$ 0.36	*
Cr	26 $\pm$ 14	*
Cu	12 $\pm$ 4	*
Fe	19958 $\pm$ 9287	12602 $\pm$ 7535
Mn	-	442 $\pm$ 288
Pb	65 $\pm$ 44	61 $\pm$ 59
Zn	104 $\pm$ 56	114 $\pm$ 34

*value below detectability

C. Sedimentation Rates and Sediment Age.

The relative age of the sediments of Webster Lake was estimated using lead concentration as an indicator. The increase in lead concentration at the 5.5 inch level (Figure VIII-6) corresponds to the introduction and increased use of leaded gasoline during the 1920's while the slight decline at the two inch layer can be attributed to the introduction of unleaded gasoline during the early 1980's. Utilizing these two dates, and assuming the surface corresponds to 1988 when the core was removed, relative sedimentation rates can be estimated at 0.06 inches (1.5 mm) year^{-1} from the two inch to the 5.5 inch layer.

These values correspond to others found in the literature. The Connecticut Department of Environmental Protection estimated that 2.0 feet (0.61m) of sediment had been deposited in eutrophic Lake Lillionah between 1955 and 1980. This equals a sediment deposition rate of approximately 1 in. (2.5 cm) yr^{-1}. Sedimentation in Lake Lillionah is unusually high, as compared to most Connecticut lakes, in that Lillionah experiences dense summer blooms of blue-green algae and receives indirect discharge of treated wastewater from an upstream sewage treatment plant. Peterson (1973) discusses sedimentation rates for Lake Trummen, located in Sweden. Approximately 40 cm of FeS-colored (black) fine sediment was deposited over a period of 25 years, or at a rate of about 0.6 in. (1.6 cm) yr^{-1}. Lake Trummen was also subject to the discharge of wastewater effluent for many years, and the significance of internal nutrient recycling was well documented. At mesotrophic Stockbridge Bowl, located in Stockbridge, Massachusetts, Ludium (1975) reported a much lower sedimentation rate of 0.12 inches (3.0-3.2 mm) year^{-1}. The Maine Department of Environmental Protection assumes an approximate sedimentation rate of 0.08 inches (2.0 mm) year^{-1}.

D. Sediment Metals and Phosphorus

Toxicity values presented in the following discussion are for concentrations measured in the water and not in the sediment. Elevated metal concentrations would not be expected to be measured in lake water unless low pH values (below 5.0 units) were commonly measured within the lake.

1. Recoverable Aluminum

One of the most abundant elements on the face of the earth, aluminum occurs in many rocks but never as a pure metal in nature. Although the metal itself is insoluble, many of its salts are readily soluble.

The toxicity of aluminum to the aquatic biota has been reviewed quite extensively with the recent association of resolublization of aluminum in acidic waters. Aluminum toxicity does not appear to be a significant problem, as long as pH is controlled and residual dissolved aluminum is not allowed to reach levels in the area of 50 ug Al/L. In areas where lakes have low ANC and acid rainfall is significant, lowering of lake pH could occur with a sudden increase in aluminum and probable toxic affects to the lake biota.

Aluminum concentrations in Webster Lake (Table VIII-3, Figure VIII-1) sediments exibited a wide range of values. The maximum concentration observed was 20,900 mg/kg (1"-2" segment), while the minimum was 4,260 mg/kg (7"-11" segment). The range of these two values is over 16,600 mg/kg. Aluminum concentrations observed in the upper five inches of the sediment core were twice as high as concentrations in the lower six inches. Possible explanations of recent elevated aluminum concentrations include the leaching of parent bedrock from acidic precipitation and an increase of outboard motor use. Most of the current engine blocks are casted from aluminum. The wear and tear of these metal components produce tiny fragments which exit the motor into the water with the dispelled oil.

Aluminum concentrations analyzed at Webster Lake fall into the mid range of sediment concentrations, compared to other analyzed sediment cores in New Hampshire (Table VIII-1).

2. Recoverable Cadmium

In the elemental form, cadmium is insoluble in water. It occurs in nature largely as a sulfide salt. Cadmium is used in metallurgy to alloy with copper, lead, silver, aluminum and nickel. It is also used in electroplating, ceramics, photography and in insecticides.

Webster Lake sediment cadmium levels ranged from below detectability (less than 0.5 mg/kg) in the 5 to 11 inch layers to 1.4 mg/kg in the 3 to 5 inch layer (Table VIII-3, Figure VIII-2). Concentrations declined in the sediment sections as the upper layers were reached. Cadmium concentrations measured in Webster Lake are below the detection limits of other analyses conducted in other New Hampshire lakes (Table VIII-1).

Table VIII-3.
Concentrations of Metals recovered from the analysis of
Webster Lake Sediments

		Recoverable Metal Concentration(mg/kg)							
Sediment Section (inches)	Dry Wt (gms)	Al	Cd	Cr	Cu	Fe	Mn*	Pb	Zn
0 - 1	1.000	20500	1.0	36	17	26000	798	94	140
1 - 2	1.000	20900	0.9	35	13	27700	770	86	140
2 - 3	1.000	20500	1.2	42	15	26400	596	106	150
3 - 5	1.001	17900	1.4	25	12	22778	634	84	130
5 - 7	1.001	9500	<.5	<10	<10	11588	320	14.8	46
7 - 11	1.003	4260	<.5	<10	<10	5284	145	3.2	19

*Manganese analized using hot plate method of digestion.

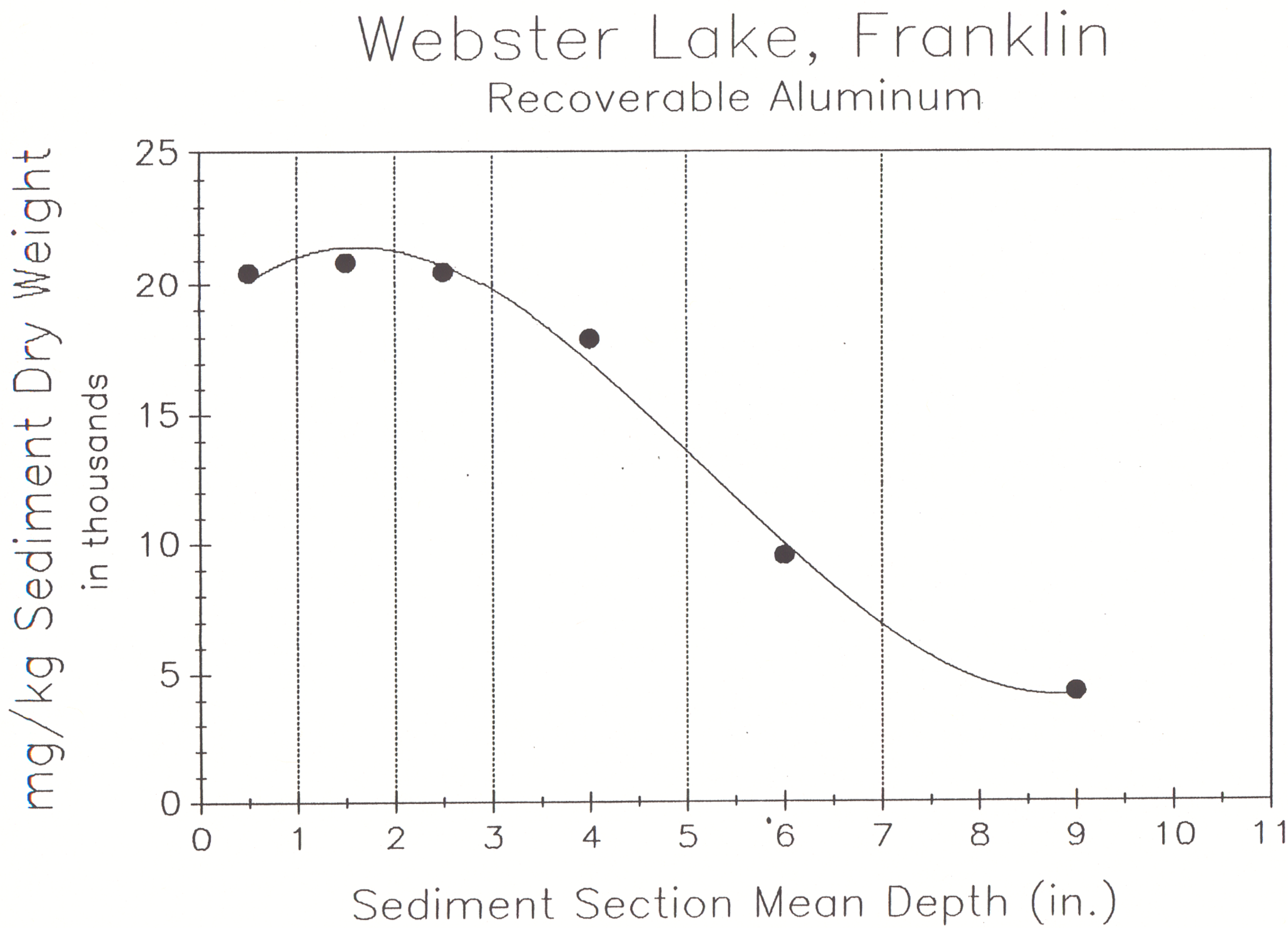

Figure VIII-1. Recoverable Aluminum Concentrations in Webster Lake Sediments.

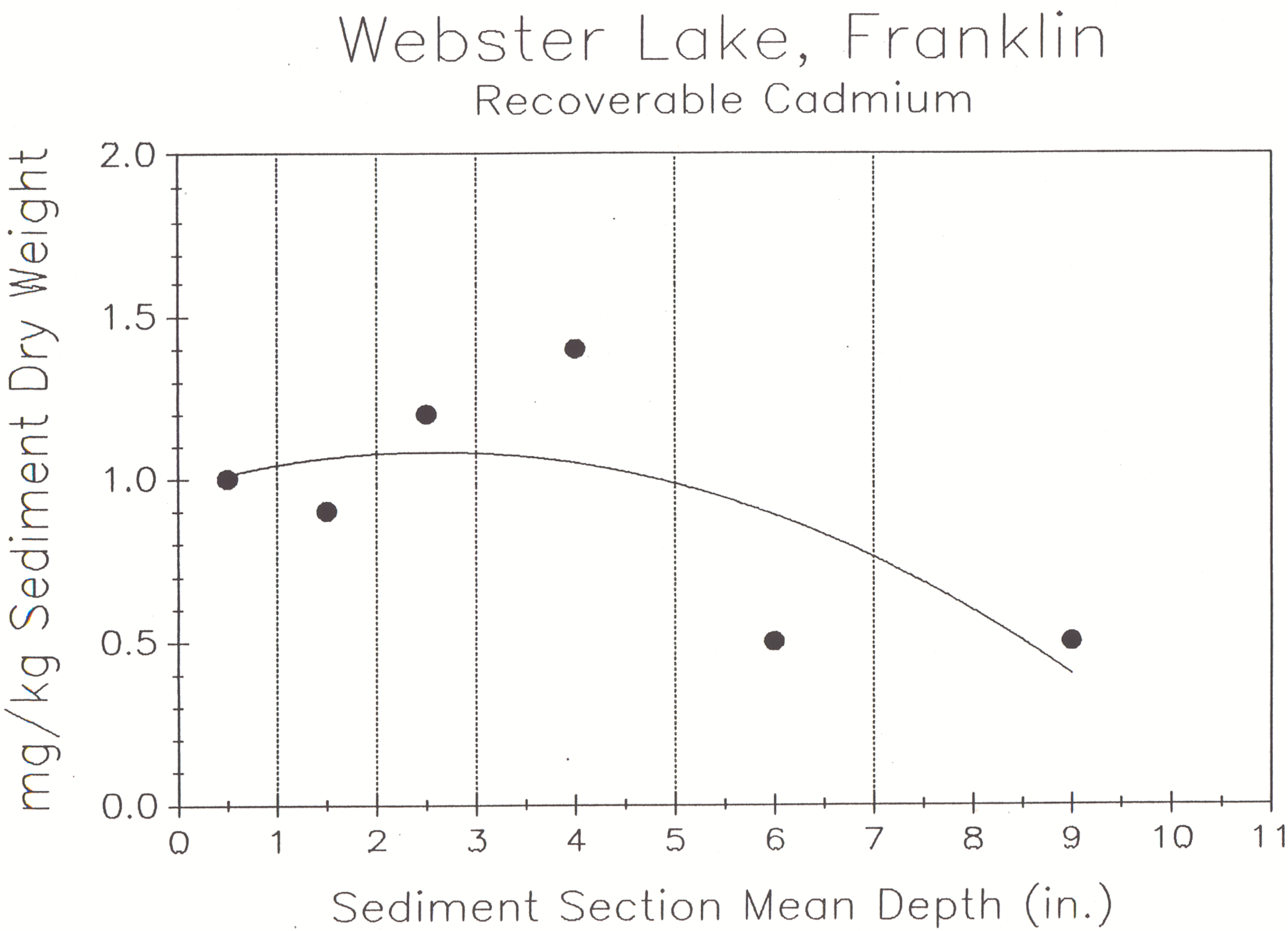

Figure VIII-2. Recoverable Cadmium Concentrations in Webster Lake Sediments.

3. Recoverable Chromium

Chromium is seldom found in natural water. Chromium salts are primarily used in the manufacture of paints, dyes, ceramics, photographic material, and glass products. Chromium is usually discharged from these industries and from cooling water from refrigeration systems where it is utilized to retard corrosion (Water Quality Criteria, 1972).

Recoverable chromium concentrations in Webster Lake sediments ranged from below the detection level of the method (10 mg/kg) to 42 mg/kg in the two to three inch layer (Table VIII-3). Chromium levels increased at the five inch layer to a mean 35 mg/kg for the upper segments of the core (Figure VIII-3).

4. Recoverable Copper

Copper salts occur in natural surface waters only in trace amounts, up to about 50 ug/L, and their presence is frequently due to the use of copper sulfate for the control of nuisance plankton species. Copper is used in many alloys, insecticides, fungicides, and wood preservatives.

Webster Lake sediment copper concentrations ranged from less than 10 mg/kg (below dectability) in the bottom six inches to 17 mg/kg in the top inch of the core section (Figure VIII-4) (Table VIII-3). Concentrations measured in all layers of Webster Lake sediment were lower than other measured concentrations in New Hampshire (Table VIII-1).

Copper Sulfate was applied as an algicide to Webster Lake each August from 1975 to 1978. Application rates were from 200 to 1,100 pounds administered to the shoreline area. These applications appear to manifest themselves slightly in the two to three inch layer. However, the increase in this section may be due to background copper as well.

5. Recoverable Iron

Iron is the fourth most abundant, by weight, of the elements that make up the earth's crust. Common in many rocks, it is an important component of many soils, especially the clay soils.

Recoverable iron concentrations in Webster Lake ranged from a minimum of 5,284 mg/kg in the 7-11 inch sediment layer to 27,700 mg/kg in the 1-2 inch section (Table VIII-3). Iron concentrations were observed to be lowest in the

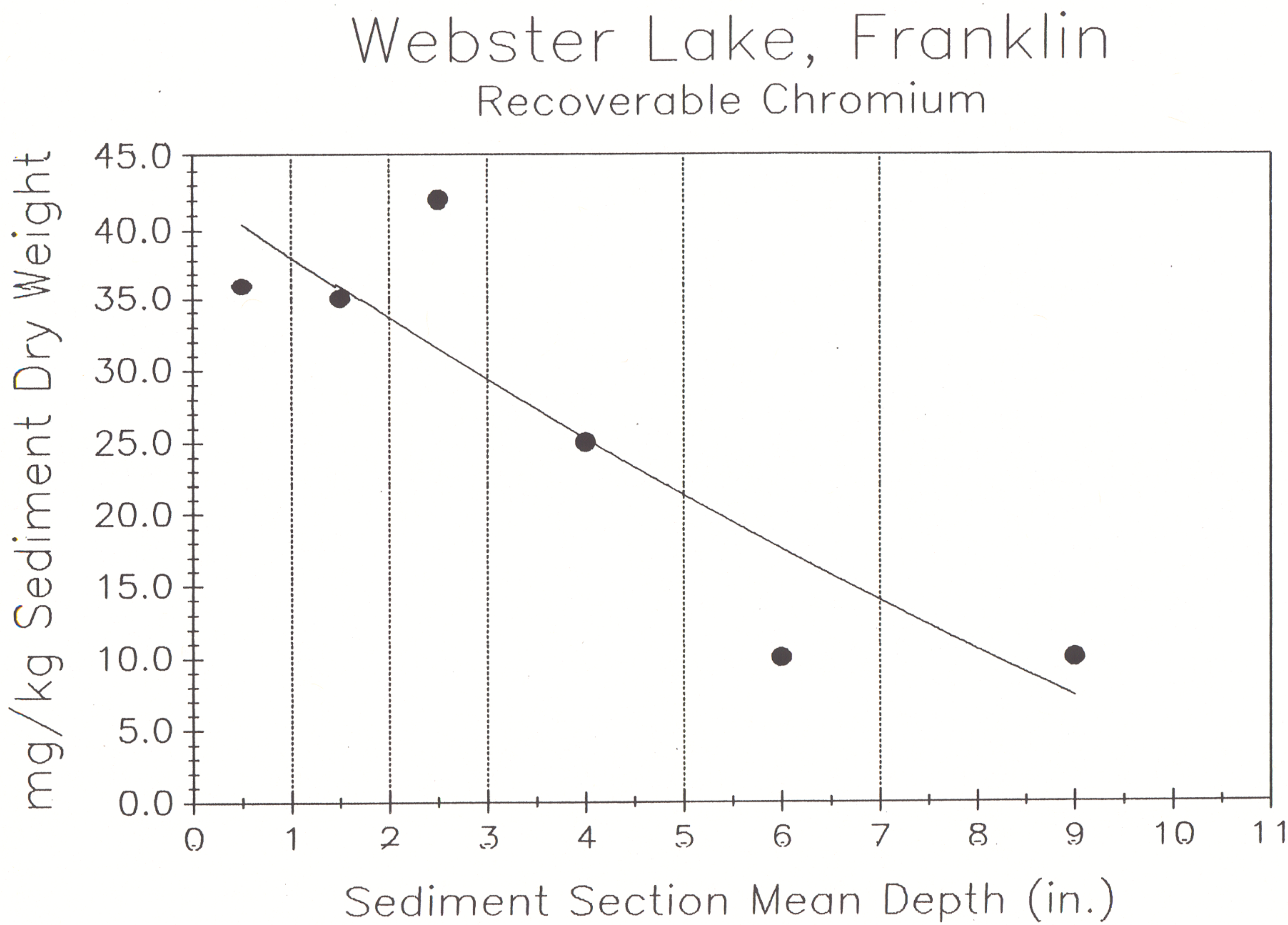

Figure VIII-3. Recoverable Chromium Concentrations in Webster Lake Sediments.

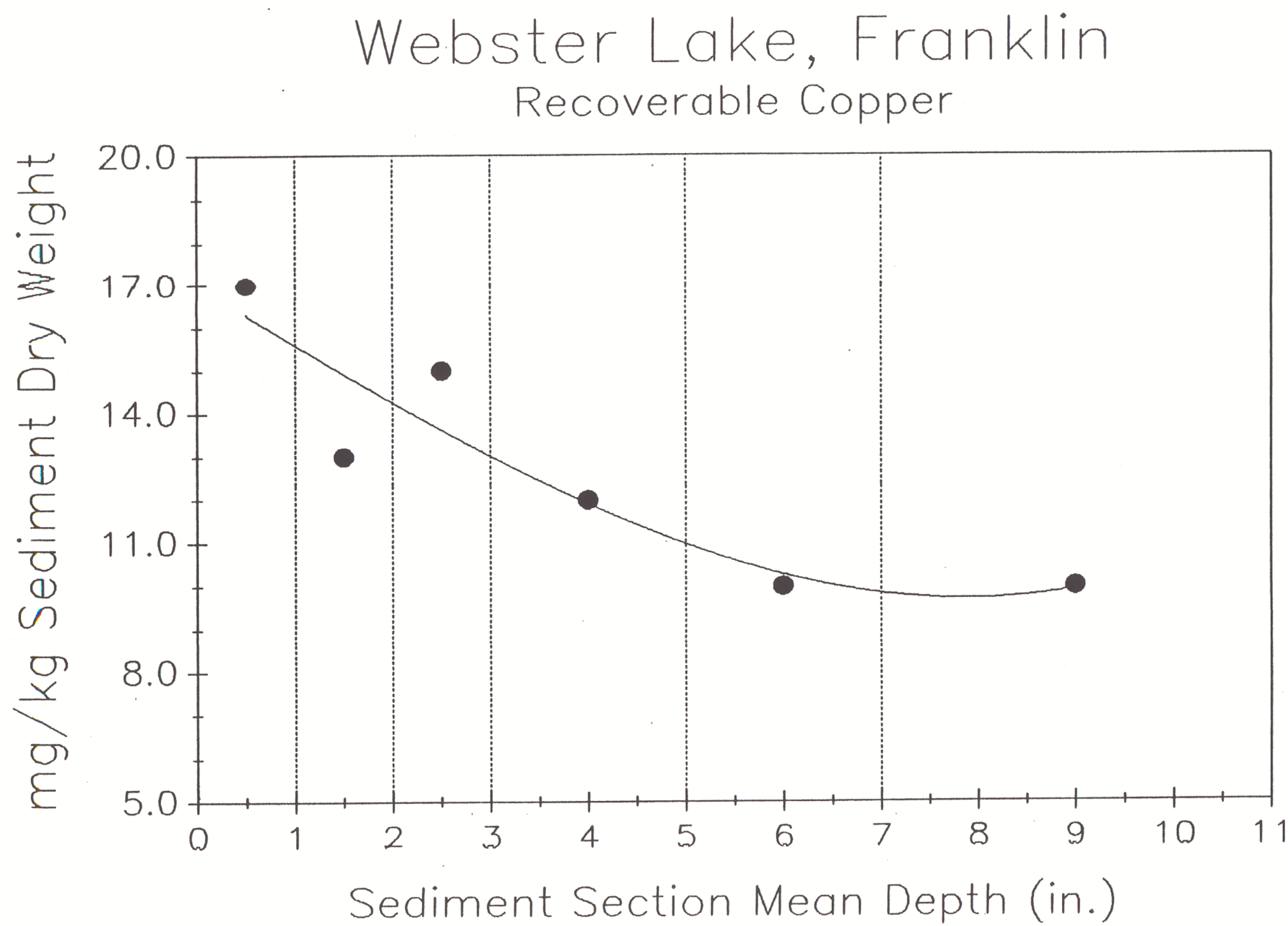

Figure VIII-4. Recoverable Copper Concentrations in Webster Lake Sediments.

deepest section of the sediment core and to progressively increase in concentration to the 0 - 3 inch layers (Figure VIII-5). In comparison with other sediment studies conducted, Webster Lake sediments contain moderate concentrations of recoverable iron (Table VIII-1).

6. Recoverable Lead

Leaded gasoline, introduced in the 1920's, has been largely blamed for the increased levels of lead observed in the aquatic environment. The solubility of lead compounds in water depends heavily upon pH. Fish kept in water of pH 6.0 concentrate almost three times more lead than fish kept in water of pH 7.5. This is of startling significance for the northeast where lake waters are generally poorly buffered and acid precipitation is further decreasing the pH in many of our lakes and ponds.

Recoverable sediment lead concentrations ranged from 3.2 mg/kg (7-11 inches) to 106 mg/kg (2-3 inches) (Table VIII-3). Lead concentrations were lowest in the bottom six inches of the Webster Lake sediment core (Figure VIII-6). Concentrations increased significantly from the 5 inch until the two inch section. Lead concentrations in the top two inches decreased slightly, from the 2 to 3 inch section, but continued the increasing lead concentration when compared to the lower layers. Sediment lead found in Webster Lake was moderate when compared to other sediment studies conducted.

7. Recoverable Manganese

Manganese is another common metal found in the earth's crust. Although not considered toxic, this metal, even in low concentrations, can cause aesthetic problems for water consumers. Manganese can cause abnormal taste, stain plumbing fixtures and clothes and accumulate in the plumbing system as deposits.

Manganese concentrations of Webster Lake ranged from 137 mg/kg in the deepest section of the core (11-13 inches) to 798 mg/kg at the surface of the sediment (Table VIII-3). Manganese concentrations increased gradually from the bottom to the top of the core (Figure VIII-7). Manganese concentrations at the surface of Webster Lake sediments were similar to the previously observed highest concentration at French's Pond in Henniker (832 mg/kg).

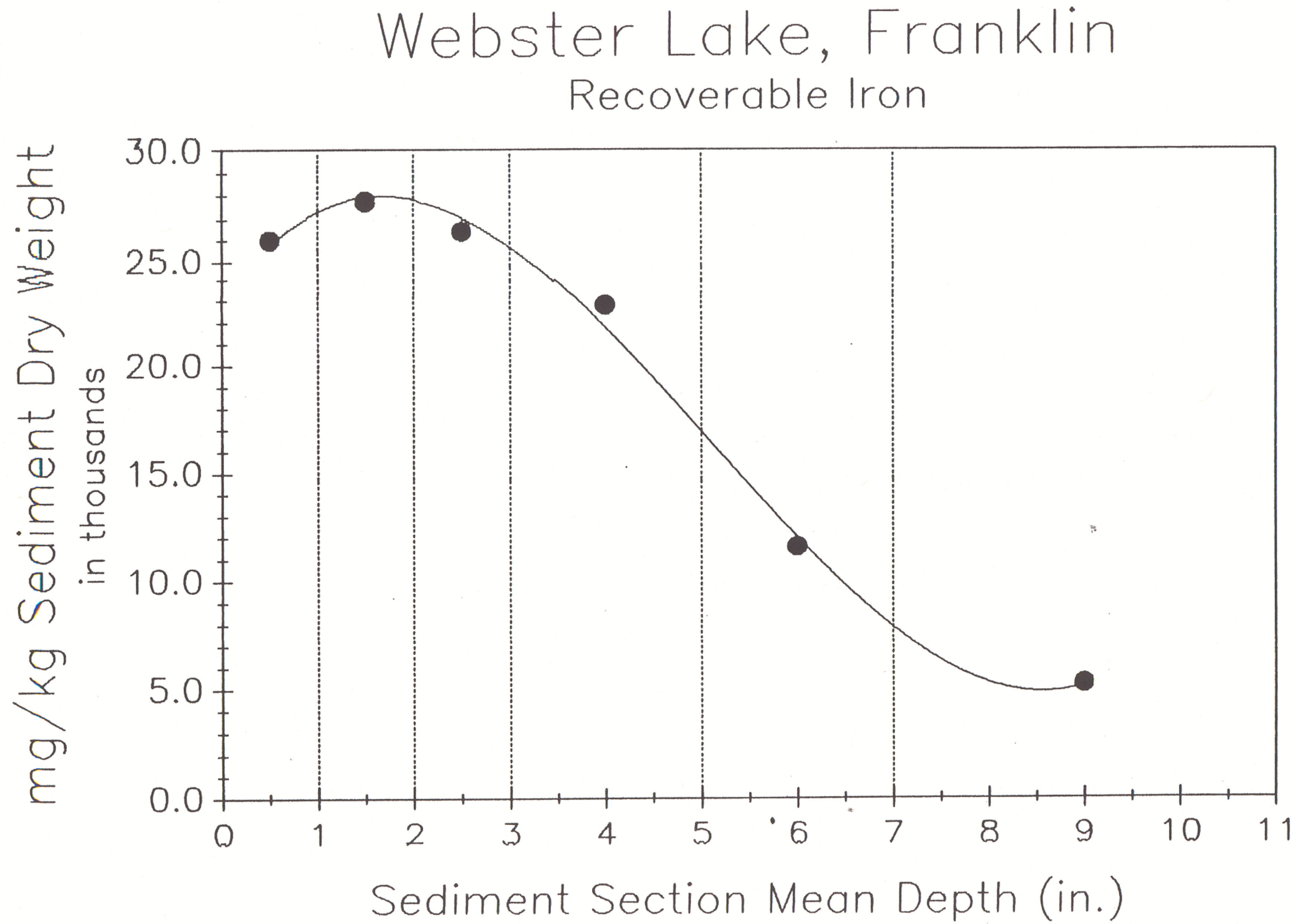

Figure VIII-5. Recoverable Iron Concentrations in Webster Lake Sediments.

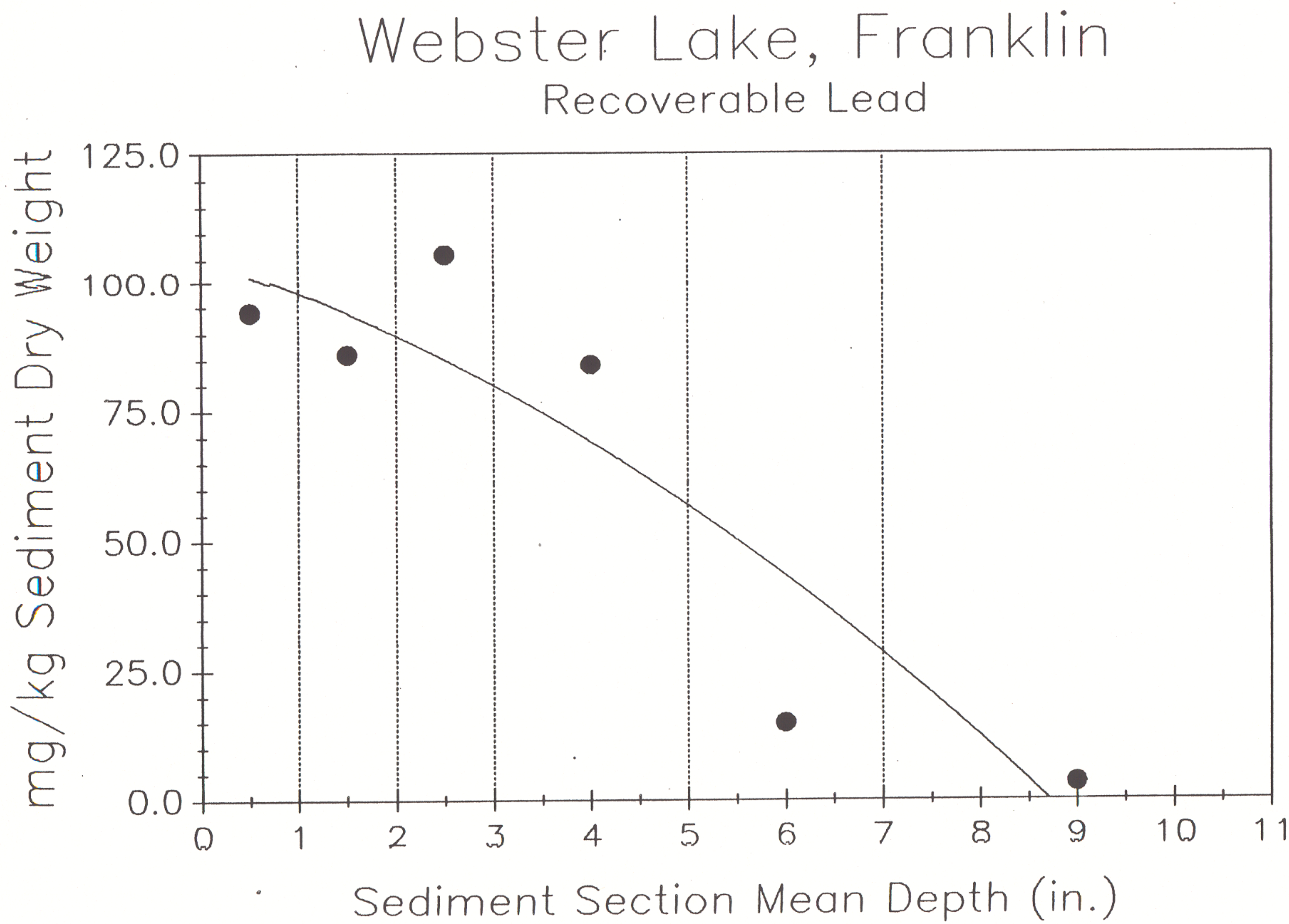

Figure VIII-6. Recoverable Lead Concentrations in Webster Lake Sediments.

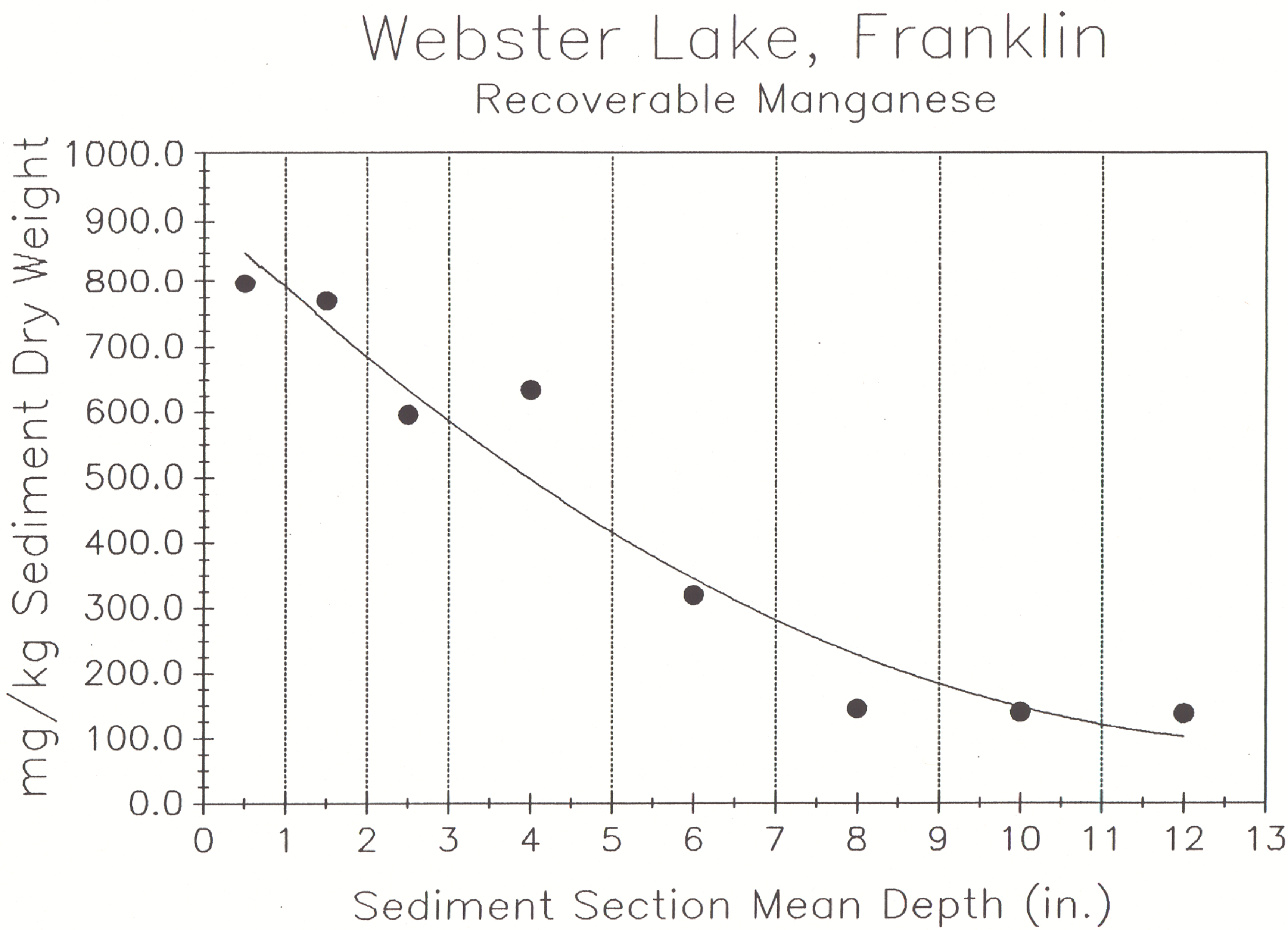

Figure VIII-7. Recoverable Manganese Concentrations in Webster Lake Sediments.

8. Recoverable Zinc

Compounds of zinc with the common ligands of surface waters are soluble in neutral and acidic solutions, so that zinc is readily transported in most natural waters and is one of the most mobile of the heavy metals. Zinc is used for the anti-corrosive coating in galvanized metals and rubber products.

Most of the zinc introduced into the aquatic environment is partitioned into the sediments by sorption onto hydrous iron and manganese oxides, clay minerals, and organic materials. All zinc forms are potentially toxic if they can be sorbed or bound by biological tissue.

Sediment zinc concentration increased from the deeper sections of the core to the surface section (Figure VIII-8). A minimum zinc concentration of 19 mg/kg was measured in the 7-11 in. section while the upper three sections contained between 140 and 150 mg/kg (Table VIII-3). Comparisons of sediment zinc concentrations in other surveys reveal that Webster Lake contained a lower concentration in the upper sediment sections (Table VIII-1).

9. Recoverable Phosphorus

The measurement of phosphorus concentration in a lake gives an indication of the extent of nutrient enrichment. The amount of phosphorus in New Hampshire lakes determines the level of plankton growth. Lake sediments often act as sinks and accumulate high concentrations of phosphorus over long periods of time. Phosphorus which has accumulated in the deep water sediments of a lake may be released into the water when the physical, biological and chemical conditions become conducive for its release. Usually, this release occurs during the summer months. If stratification is weak, this phosphorus migrates to the metalimnion to be utilized by the plankton community; otherwise, much of this hypolimnetic phosphorus is distributed to the entire water column during the fall overturn.

The identification of sediment phosphorus concentration is important to the phosphorus budget and the assessment of restorative lake techniques. Spatial distribution of sediment phosphorus with depth is important in the evaluation of lake restoration techniques and their feasibility. The uniform distribution of high concentrations of phosphorus throughout the sediment column would obviously make dredging an unfeasible restorative technique. However, hypolimnetic sediment phosphorus inactivation, as a restorative technique, might be a solution for this type of problem.

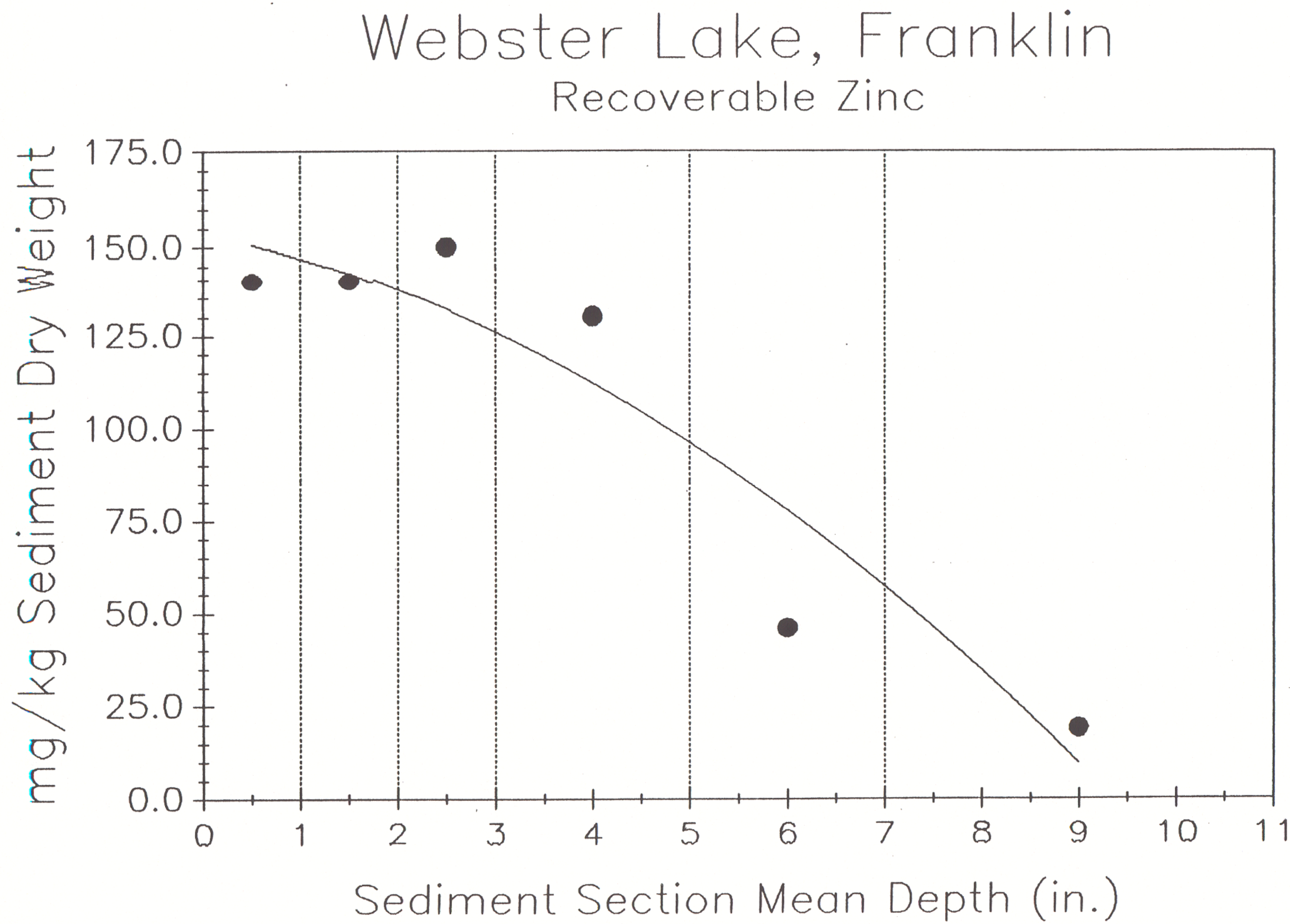

Figure VIII-8. Recoverable Zinc Concentrations in Webster Lake Sediments.

Most studies show that lake sediments typically contain 1000-2000 mg/kg of recoverable phosphorus. In 27 borderline mesotrophic/eutrophic lakes located in Massachusetts, the mean concentration was 1,268 mg/kg, while concentrations of recoverable sediment phosphorus in 15 New Hampshire lakes ranged from 100 to almost 14,000 mg/kg. Sediment phosphorus concentrations in Lake Washington, Washington State, ranged from 1000 to 6000 mg/kg while the range in Lake Shagawa, Minnesota, was 1000-5000 mg/kg.

Mean recoverable phosphorus in Webster Lake ranged from 1564 mg/kg (9-11 inch layer) to 4979 mg/kg (2-3 inch layer) (Table VIII-4). Sediment phosphorus concentrations found in the upper five inches of the sediment core were elevated over those of the lower four inches (Figure VIII-9). The 5-7 inch sediment layer appears to be a transition area between the decreased concentrations found in the lower layers and the increased concentrations observed in the upper sediment layers.

Moderate to low concentrations of sediment phosphorus were measured in Webster Lake when compared to other sediment studies conducted in New Hampshire. Unfortunately, increased phosphorus concentrations were measured within the sediment water interface. The combination of hypolimnetic anoxia and high surface sediment phosphorus is chemically conducive to the release of phosphorus to the hypolimnion. The accumulation of hypolimnetic phosphorus during the sampling program confirms that sediment phosphorus release is occurring during the summer months.

Table VIII-4.
Recoverable Phosphorus Concentrations found in Webster Lake Sediments.

Sediment Section (inches)	N	Recoverable P (mg/kg) Min	Max	Mean
0 - 1	7	4115	5195	4735
1 - 2	7	3955	5191	3889
2 - 3	6	4106	6096	4979
3 - 5	6	3981	4462	4457
5 - 7	7	1978	3086	2584
7 - 9	6	1205	2052	1676
9 - 11	6	512	2439	1564

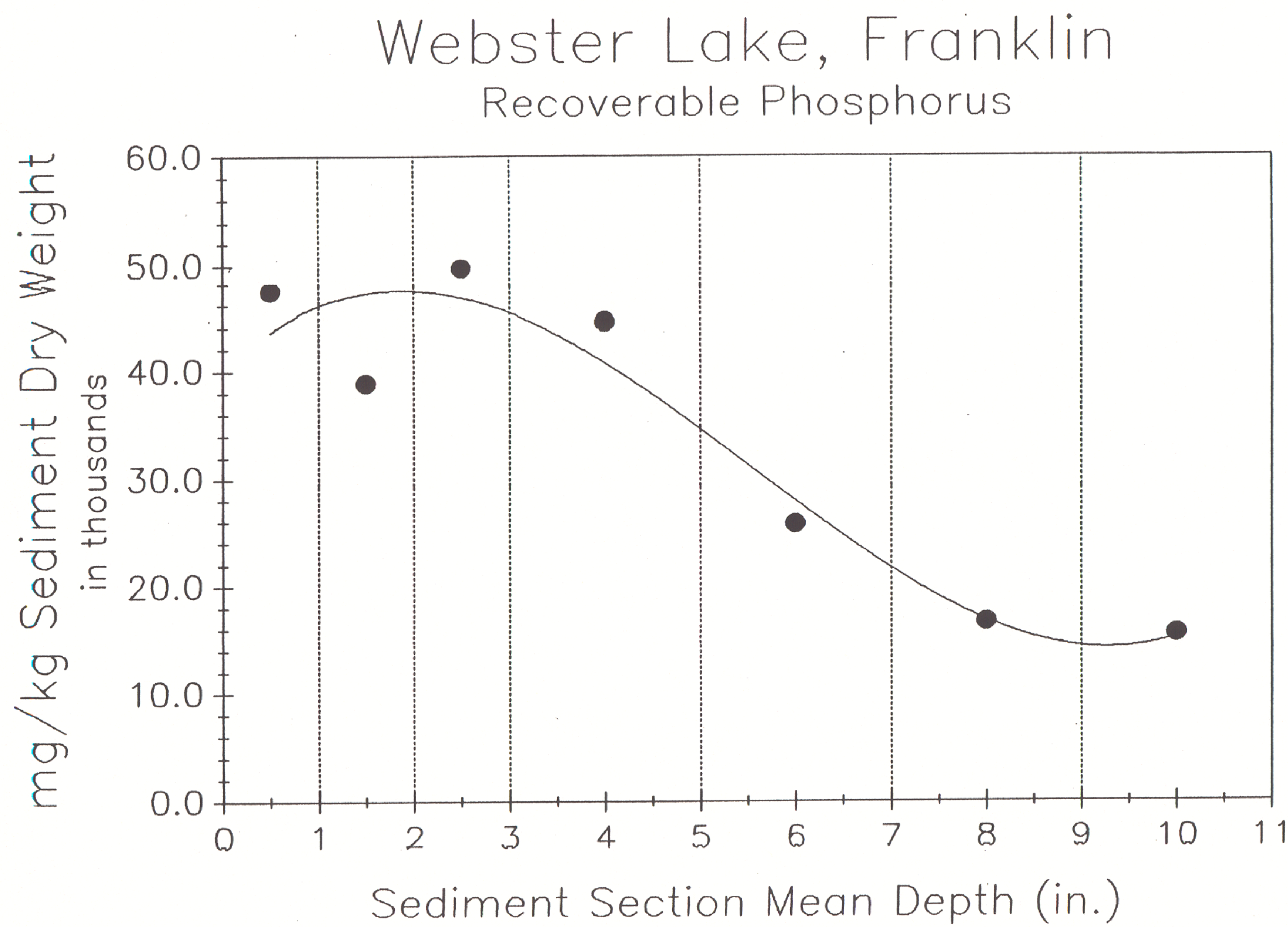

Figure VIII-9. Recoverable Phosphorus Concentrations in Webster Lake Sediments.